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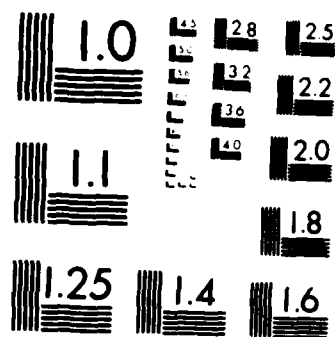
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This contract was for the support of Mr. Dan Wiley and was a part of the ARO Fellowship program. This report describes the selection process, academic record and progress of the recipient, and his research work to date. His research work included first the testing and evaluation of a potential mm/submm (millimeter and submillimeter) source developed by ETDL and more extensive investigations of the properties of systems in the mm/submm spectral region at temperatures below 4K.

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Final Report

Frank C. De Lucia

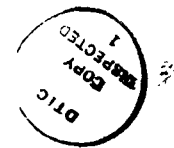
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Abstract

This contract was for the support of Mr. Dan Wiley and was a part of the ARO Fellowship program. This report describes the selection process, academic record and progress of the recipient, and his research work to date. His research work included first the testing and evaluation of a potential mm/submm (millimeter and submillimeter) source developed by ETDL and more extensive investigations of the properties of systems in the mm/submm spectral region at temperatures below 4K.

Graduate Fellowships in Near Millimeter Waves and Microelectronics

Recruitment:

This contract was for the support of an Army Research Office Graduate Fellowship. An extensive national search was conducted both by means of the mailings of printed materials and a number of personal contacts. As a result of this search, Mr. Dan Wiley was identified as the top candidate, the Fellowship was offered to him, and he accepted. Mr. Wiley received his undergraduate degree from Dartmouth, where he had worked for the previous two years in the laboratory of another ARO contractor, John Walsh.

Academic Work:

Dan made an outstanding record in the course work required for his Ph. D., making mostly "E's" (Exceptional, the highest grade). In my Quantum Electronics class, as the most junior student in the course, he was at the top of a group that contained several other strong students. He then passed his preliminary examination and became a full time researcher.

Research Work:

His first laboratory work was helping with what was to become the thesis work of Rod McCormick. During that time he he gained basic experience about millimeter waves, a variety of laser systems, and computer based data acquisition and processing.

As a result of a several conversations between our laboratory and Dr. Gerald Iafrate of ETDL, Dan became involved in a project to use our very sensitive ^3He (0.3K) detectors to test a new type of mm/submm source conceived by Dr. Iafrate. Since in its initial configuration it was be expected to be a very low power device, the use of our very sensitive detector techniques was necessary for its evaluation. Dr. Dorian Smith of ETDL brought the device to our laboratory and a test system was set up and a number of measurements carried out. Radiation was detected with a S/N of about 100, but it was unclear whether or not the source of the detected radiation was electronic or thermal.

Thesis Research:

Dan has devoted most of his research time to a project that will form the basis of his thesis, the study of mm/submm phenomena at very low temperatures ($\sim 1\text{K}$ to 4K). This project has been very successful and has drawn considerable attention in the scientific community. At a meeting this summer, Dan's paper drew a "standing room only" audience, most of whom left immediately after Dan's presentation.

The basic idea of Dan's experiment is to create an environment in which gas phase systems can be studied at temperatures near absolute zero. The difficulty is that all gasses that interact with mm/submm radiation condense at much higher temperatures. One of the motivations for this work is the desire to be able to build quantum electronic devices in the mm/submm that have the attributes of optical systems at room temperature. The factor that is the best measure of this is the ratio $h\nu/kT$. For systems in the mm/submm to have the same ratio as optical systems at ambient temperature requires a temperature of about 4K . This ratio is important in quantum electronic devices because it is intimately related to relaxation rates.

The basic idea is straightforward and is shown in Figure 1. In it the copper sample chamber shown is immersed in liquid helium to maintain the appropriate temperature in the 1K - 4K range. The cell is then filled with a helium buffer gas at a pressure near 10 mTorr . A thermally insulated tube is maintained at approximately room temperature and used to inject small amounts of warm electromagnetically active gas into the side of the chamber. The active gas then random walks its way toward the walls of the chamber where it condenses. Along the way the collisions with the cold He gas cool the active gas. Since under typical conditions it takes $10\,000$ collisions to reach the wall, but only about 100 collisions to cool the active gas, the result is a chamber that contains an active gas at a pressure far below its condensation point. Figure 2 shows a more complete drawing of the apparatus that includes the helium reservoirs, heat shields, etc.

Dan's first experiments have been designed to study the relaxation properties of the states of the active species in this collisionally cooled environment. First, it should be stated that what happens in this new physical regime is a very open question. As a result it is of considerable interest both on fundamental and practical grounds. Ordinarily, it is assumed that a collisions will completely interrupt the quantum phase of the system and, owing to the small energy level spacing in comparison to kT , cause a thermal relaxation. However, in this regime, where $h\nu > kT$, the semi-classical

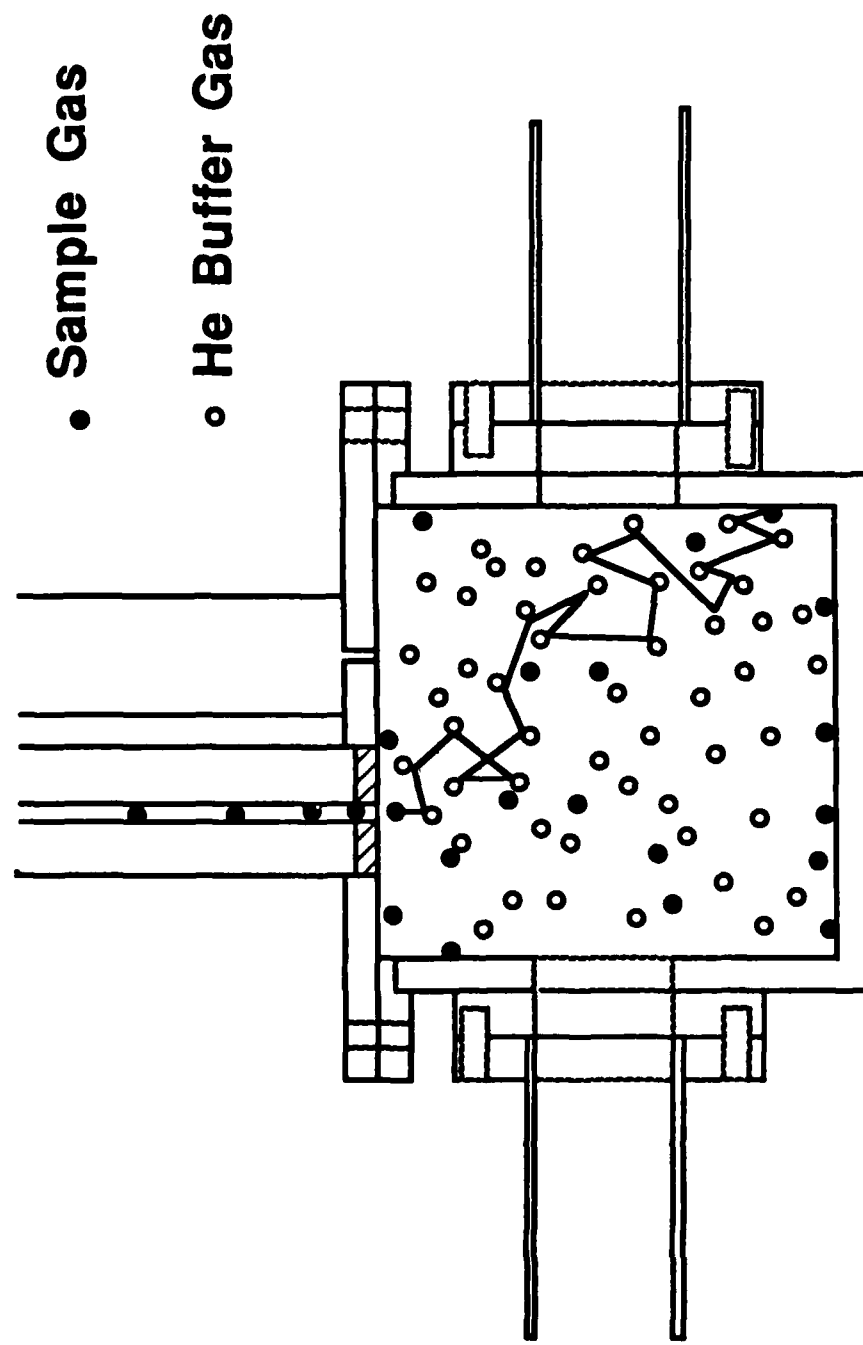


Figure 1

LOW TEMPERATURE SPECTROSCOPY CELL

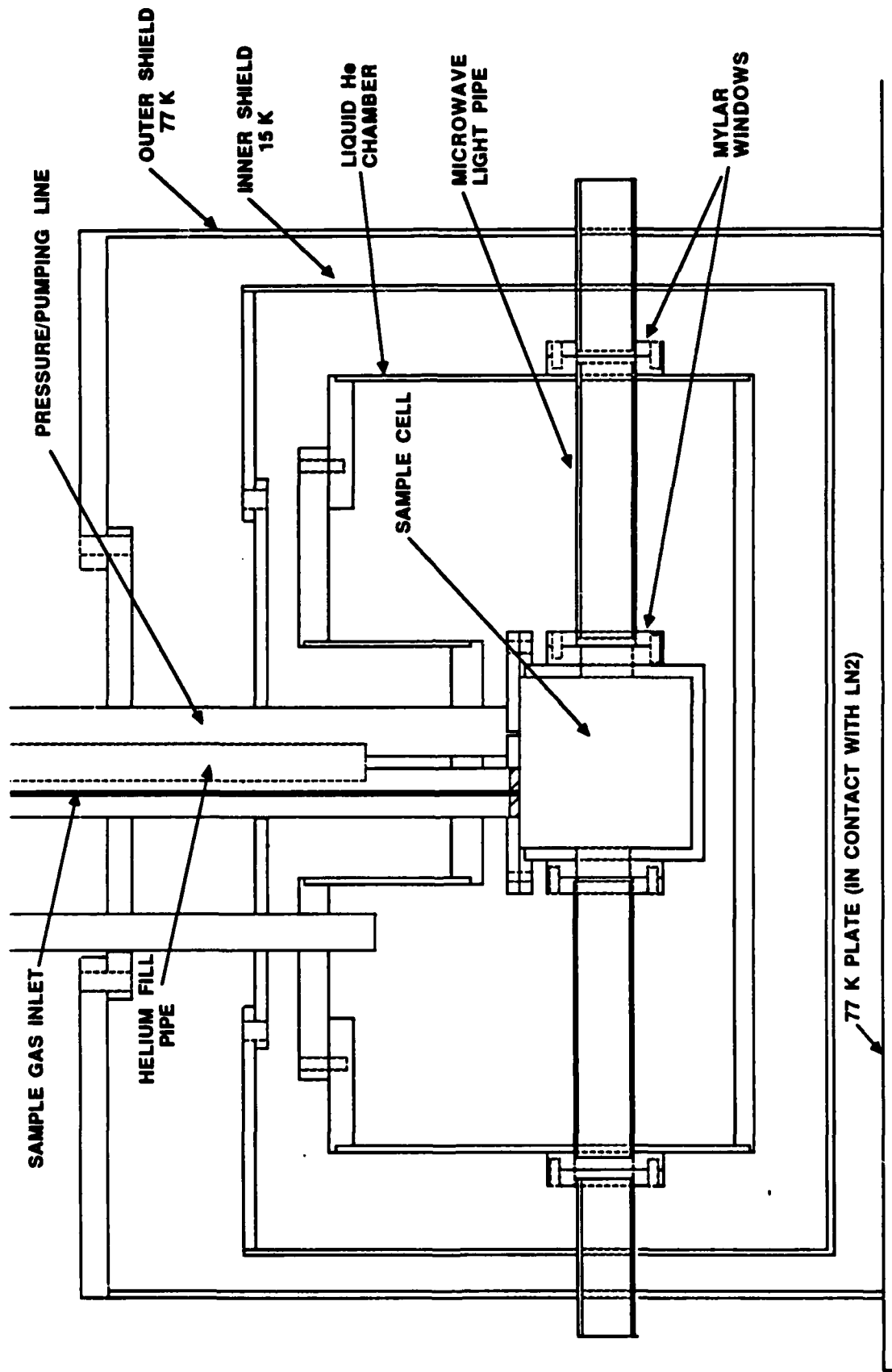


Figure 2

expectation is that no relaxation will occur, because the collision does not contain enough energy to force a transition.

A full close coupled quantum mechanical calculation shows that the situation is more complicated and depends much more strongly on the details of the intermolecular potential than do room temperature interactions. Our first results motivated a detailed theoretical calculation of this regime by Sheldon Green (J. Chem. Phys. 82, 4548 (1985), J. Chem Phys. 85, 1333 (1986)). Briefly put, these calculations showed that if the interaction potential had even a shallow attractive minimum in its radial dependence, that short lived collision complexes would be formed that significantly altered the semi-classical expectations. These short lived complexes represent the "ultimate relaxation," the temporary disappearance of the species altogether, with its reemergence in a completely different state. Figure 3 show that most direct measure of this phenomenon, the collisional cross section for pressure broadening. In this figure, it can be seen that the lowest curve (which represents a purely repulsive potential) decreases toward zero as the collision energy is reduced. This is in accordance with the semi-classical expectation that when there is not enough energy in the collision to force a transition, nothing happens. The intermediate curve includes a modest amount of attractive potential and the top curve includes that full potential provided by a good quantum calculation. In the latter two cases the sharp resonances represent the the energies at which the numerical solution to the Schrodinger Equation correspond to the formation of collision complexes.

Experimentally, one observes a thermal average of the energy cross section shown in Figure 3. This is shown in Figure 4 along with the results of Dan's measurements. These measurements show that rather than the relaxation cross section increasing with reduced energy as predicted by the calculations discussed above, that they are beginning to decrease. We are currently working to reduce the temperature of these measurement to see if this trend continues. Other systems will also be studied.

This experiment has worked so well that it has opened up to us as well as to a number of other laboratories a number of new research opportunities. Of primary interest to us are those associated with the relaxation studies discussed above and their implications for quantum electronic devices. However, there are a whole host of opportunities available to workers in a number of related fields including the study of weakly bound states and the use of the technique to obtain significant spectral simplification.

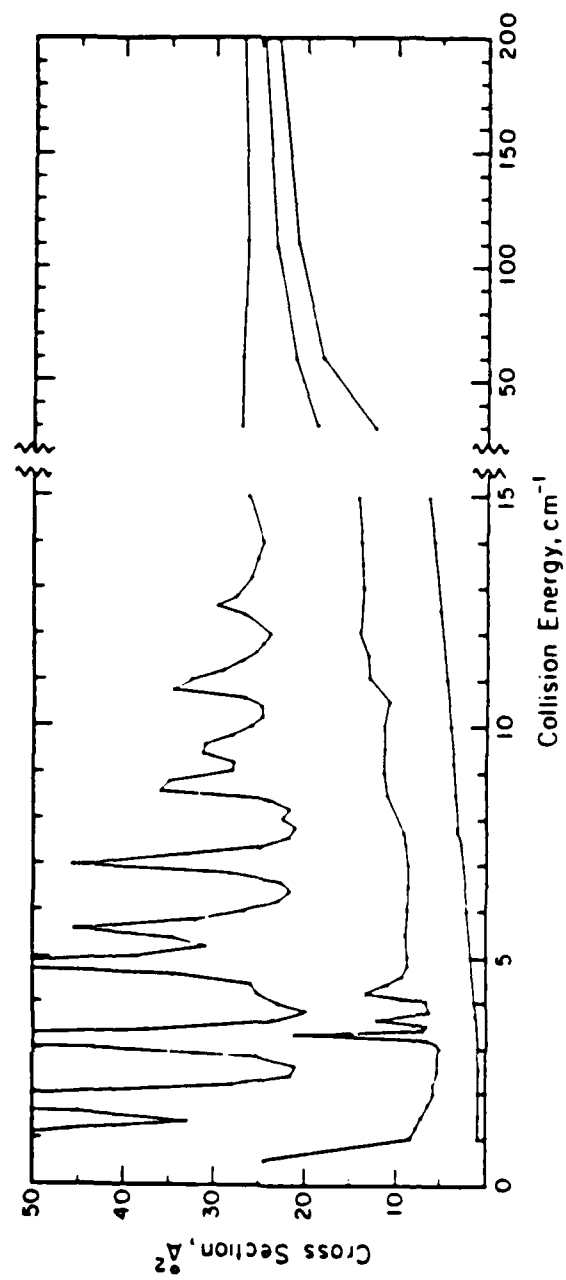


Figure 3 - Theoretical Cross Section

Cross Section vs Temperature

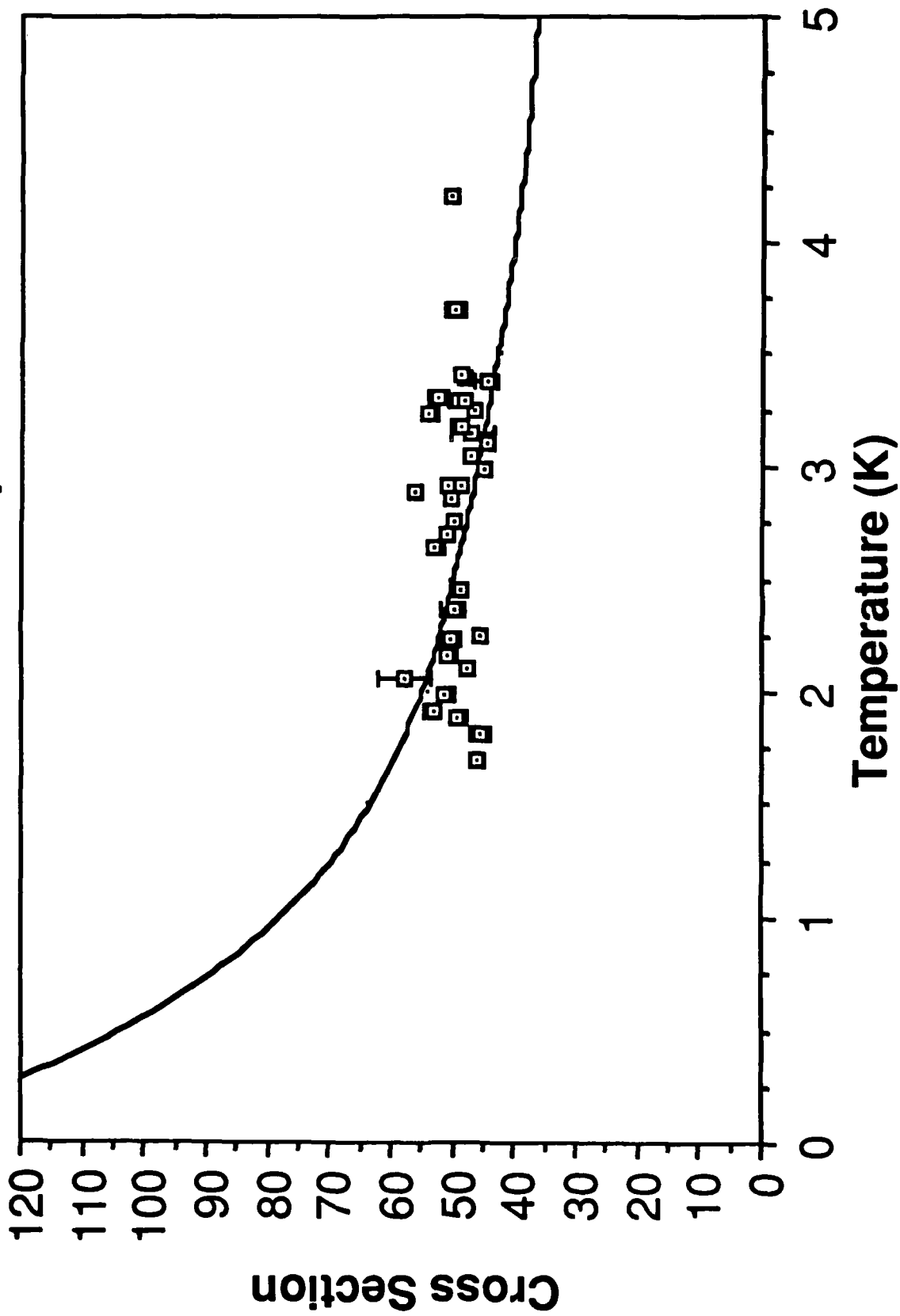


Figure 4.

Epilogue:

In retrospect, we feel very good about the selection of Dan for this Fellowship. Not only has he been an excellent student with the promise of developing into an outstanding scientist, but without the Fellowship it would have been significantly harder, if not impossible, for him to pursue a Ph. D. Thus, in the person of Dan Wiley, the ARO Fellowship Program will accomplish its major goal, the increase of the scientifically trained personnel available in the United States.

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